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Cost Analysis of Paint Waste Incineration Technology at U.S. Army Depots

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The U.S. Army Depot System Command (DESCOM) has 16 maintenance depots located throughout the U.S. Several army depots generate paint wastes that must be disposed of. These depots are located in different parts of the country, and a comprehensive strategy is required to manage the disposal of the paint wastes generated at the individual depots. Incineration is a candidate technology for disposal of such wastes. This report presents an economic analysis of developing an incineration strategy.

The economic analysis of paint waste incineration was limited to six major maintenance depots: Anniston, Corpus Christi, Letterkenny, Red River, Tobyhanna, and Tooele. These particular depots are included in the analysis because they are responsible for the majority of all paint wastes generated annually by DESCOM. Three scenarios were evaluated: 1) locating an incinerator at each depot, 2) locating an incinerator at a single site and transporting waste from other depots to this location, and 3) using multiple units at two or more depots. The analysis considers the locations of the army depots, the types and quantities of the wastes they generate, and transportation of the wastes. It also assumes that the individual army depots are equally equipped for proper management of the paint waste by the incineration tech-

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nology and that the waste can be transferred between the depots without any restrictions. It is further assumed that only incinerable paint wastes will be treated.

The results of the cost analysis indicated that locating an incinerator at each site for paint waste incineration was not economical compared with commercial disposal costs. Anniston Army Depot was estimated to be the most economical site location for handling the entire paint waste generation throughput for all six depots. This is a function of being the largest generator of incinerable paint waste material and having a central geographic location. The estimated disposal cost for Anniston to handle the entire paint waste generation throughput, however, was not shown to be economical compared with commercial disposal costs.

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SECTION 1

INTRODUCTION

Several army depots generate paint wastes that must be disposed of. These depots are located in different parts of the country, and a comprehensive strategy is required to manage the disposal of the paint wastes generated at the individual depots. Incineration is a candidate technology for disposal of such wastes. Although a simple approach such as installing an incinerator at each of the depots could be suggested, such an approach may not be feasible for reasons such as quantities of waste generated, site difficulties, and permitting factors. Also, this approach may not be cost-effective for managing the paint wastes generated by the depots.

An economic evaluation of the options that are technically and logistically acceptable can be used to select a cost-effective strategy. For such an evaluation, all of the technically and logistically feasible alternatives must be defined. Factors related to the location of the army depots and the types and quantities of the wastes they generate must be taken into account. Factors related to transportation of the waste through neighboring communities and ability of the selected depots to manage the wastes shipped from other locations also must be examined.

This report deals with the economic analysis of developing an incineration strategy. For this analysis, it is assumed that the individual army depots are equally equipped for proper management of the paint waste by the incineration technology and that the waste can be transferred between the depots without any restrictions. It is further assumed that only incinerable paint wastes will be treated.

In addition to the lack of information about logistic factors, depot-specific information is also limited on waste generation rates, waste characterization, waste storage capacity, and space availability for installing an incineration system. Because of these information gaps, this study is designed only to provide a framework for economic evaluation of alternative incineration strategies. It will be useful in evaluating alternative strategies and in selecting a final strategy once the technical and logistic factors have been further defined.

This report is organized into four sections. Section 2 provides currently available information concerning waste generation rates and waste characterization at the army depots. Section 3 presents the cost basis for the incineration system alternatives. Section 4 discusses the cost evaluation for three options: 1) location of an incinerator at each depot, 2) location of an incinerator at a single site and transporting

waste from other depots to this location, and 3) using multiple units at two or more depots. Section 5 presents conclusions and recommendations.

SECTION 2

DESCRIPTION OF WASTE GENERATING SITES

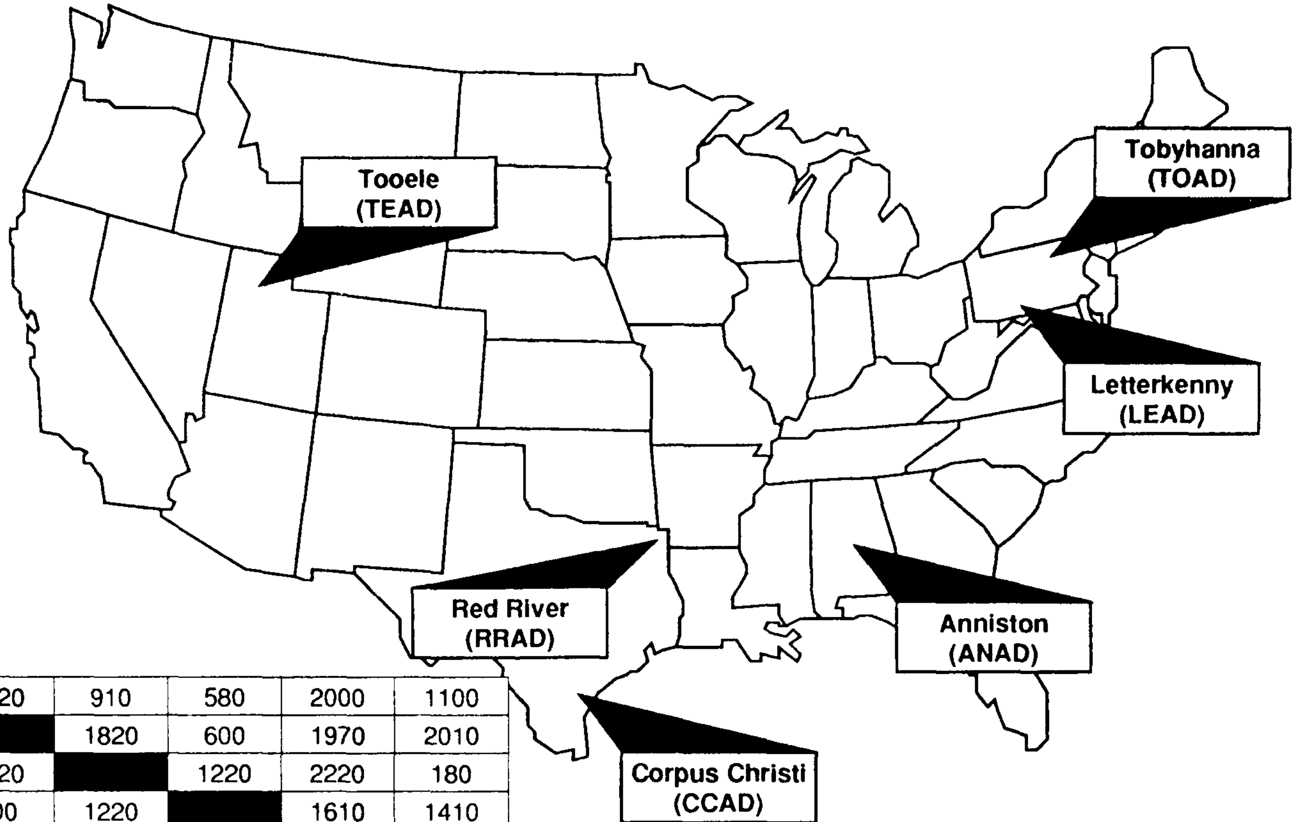
The U.S. Army Depot System Command (DESCOM) has 16 maintenance depots located throughout the country. These maintenance depots are responsible for the maintenance, overhaul, and repair of all major Army weapon systems. For the purpose of this study, the economic analysis of paint waste incineration was limited to six major maintenance depots: Anniston, Corpus Christi, Letterkenny, Red River, Tobyhanna, and Tooele. Figure 2-1 shows the locations of these depots and the approximate mileage between them. These particular depots are included in the analysis because they are responsible for the majority of all paint wastes generated annually by DESCOM.

Paint wastes include all waste material generated from both paint stripping and paint application operations. Paint stripping involves the use of either abrasive blasting or chemical stripping. The wastes generated by paint stripping operations include spent abrasive media and chemical stripper liquids and sludges. Paint application wastes vary from paint sludges and liquids to miscellaneous trash and debris. Paint waste generation rates for the depots included in this analysis range from 200 to 2100 tons per year. The remaining depots, which have much smaller paint waste generation rates, were excluded from the analysis because their current disposal practices are cost-effective. The following subsections describe each of the seven depots and present available paint waste generation rates.

2.1 ANNISTON ARMY DEPOT (ANAD)

2.1.1 Depot Description

Anniston Army Depot (ANAD) is located in northwest Alabama, approximately 10 miles west of the city of Anniston. The work performed at ANAD ranges from simple repair to the complete overhaul of combat vehicles, small arms, and missile systems. Current responsibilities include the refurbishment of the Army's M48, M60, M551, and M1 Abrams tanks. Paint wastes are generated during both paint stripping and paint application operations. A summary of ANAD's paint waste generation rates by type is presented in Table 2-1.



	ANAD	CCAD	LEAD	RRAD	TEAD	TOAD
ANAD		1120	910	580	2000	1100
CCAD	1120		1820	600	1970	2010
LEAD	910	1820		1220	2220	180
RRAD	580	600	1220		1610	1410
TEAD	2000	1970	2220	1610		2400
TOAD	1100	2010	180	1410	2400	

Figure 2-1. Location and approximate mileage between principal U.S. Army Depots.

TABLE 2-1. SUMMARY OF ANNUAL PAINT WASTE GENERATION AT ANAD[a]

Waste type	Generation rate, tons	Percent of total
Abrasive blast wastes		
Glass beads	80	4
Walnut shells	240	12
Green Lightning®	400	19
Steel shot	40	2
Aluminum oxide	40	2
Black Beauty®	827	40
Chemical stripping wastes		
Methylene chloride	[illegible]	4
Sodium hydroxide	76	4
Paint application wastes		
Water-wall paint sludge	269	13
Thinner/paint sludge	11	1
Total	2063	100

[a] Source: PEI Associates, Inc. Draft Report - Pilot Study of Paint Waste Treatment Technology Phase II Report Recommendations for Technology Development. Prepared for U.S. Army Toxic and Hazardous Materials Agency under Army Contract No. DAAA15-88-D-0001. Task Order No. 0001. September 1990.

2.1.2 Abrasive-Blasting Wastes

Six types of abrasive-blast media are used at ANAD: glass beads, walnut shells, Green Lightning,® steel shot, aluminum oxide, and Black Beauty.® A combined total of 1627 tons of abrasive shot-blast waste was generated by ANAD in 1989. The waste generation rates indicated in Table 2-1 include the projected 1990 usage of Black Beauty. Depot personnel expect that the total projected annual blast waste from the use of this material beginning in 1990 will be approximately 827 tons. All shot-blast wastes are currently disposed of as hazardous waste.

2.1.3 Chemical-Stripping Wastes

Chemical paint stripping at ANAD is accomplished by treating parts in either a methylene chloride/formic acid stripper or in a sodium hydroxide-based alkaline paint stripper. The physical state of the chemical-stripping waste residuals varies from thick slumping solids to light free-flowing sludges. In 1989, ANAD generated approximately 156 tons of chemical-stripping residuals. All chemical stripping residuals are currently disposed of as hazardous waste.

2.1.4 Paint-Application Wastes

The major paint-application waste generated at ANAD is sludge from water-wall paint-spray booths. In 1989, ANAD generated approximately 269 tons of water-wall sludge. About 11 tons of paint booth waste (thinner and other waste material) was also generated in 1989. This waste is generated during the cleaning of spray guns and hoses and the disposal of unused paint at shift changes. With the exception of the fiberglass air filters, all of the paint application wastes are considered to be hazardous waste because they exhibit the RCRA characteristic of ignitability as a result of the presence of paint solvents.

2.2 CORPUS CHRISTI ARMY DEPOT (CCAD)

2.2.1 Depot Description

The Corpus Christi Army Depot (CCAD), which is located in the city of Corpus Christi, Texas, is responsible for the repair, overhaul, and maintenance of helicopters. Paint wastes are generated during both paint stripping and paint application operations. Table 2-2 presents a summary of paint waste generation rates by type for CCAD.

TABLE 2-2. SUMMARY OF ANNUAL PAINT WASTE GENERATION AT CCAD

Waste type	Generation rate, tons	Percent of total
Abrasive blast wastes[a]		
Starbright®	229	44
Plastic beads	45	9
Glass beads/aluminum oxide	53	10
Chemical-stripping wastes[b]		
Paint stripper sludge	52	10
Paint remover stripper	1	<1
Cadmium stripper solution	4	<1
Paint application wastes[b]		
Paint waste liquid	125	24
Paint waste solid	7	1
Total	516	100

[a] Source: Personal communication from J. Holiday of CCAD, November 1, 1990.

[b] Source: PEI Associates, Inc. Trip Reports - Hazardous Waste Minimization and Control at Army Depots. Prepared for U.S. Army Toxic and Hazardous Materials Agency under Army Contract No. DAAA15-88-D-0001. Task Order No. 0004. August 1989.

2.2.2 Abrasive-Blasting Wastes

Four types of abrasive blast media are used at CCAD: Starbright,® plastic beads, glass beads, and aluminum oxide. Walnut shells were once used for depainting operations, but were found to be too aggressive on the thin metal used on many parts of the helicopter airframe. For 1990, CCAD projected that a combined total of 327 tons of abrasive shot-blast waste would be generated. The majority of shot-blast waste is generated from the use of Starbright medium (70 percent). Approximately 45 tons of abrasive shot-blast waste was projected to be generated from the use of plastic media in 1990. All shot-blast wastes are currently disposed of as hazardous waste.

2.2.3 Chemical-Stripping Wastes

Depending on the type of paint and metal substrate being stripped, chemical stripping is accomplished by treating parts in a methylene chloride/formic acid stripper, a methylene chloride/alcohol stripper, an ortho-dichlorobenzene stripper, or a

caustic paint stripper. In 1988, CCAD generated approximately 57 tons of chemical-stripping residuals. All chemical-stripping residuals are currently disposed of as hazardous waste.

2.2.4 Paint-Application Wastes

Most of the painting at CCAD is conducted in water-wall spray booths; however, some dry filter booths are also used. In 1988, CCAD generated approximately 132 tons of paint application wastes. The majority of this waste material is paint sludge generated by water-wall paint booths. The physical state of paint application wastes varies from free-flowing liquids (e.g., waste solvents) to rubbery solids (e.g., congealed waste paint) to miscellaneous trash and debris (e.g., fiberglass air filters, floor scrapings, and empty paint cans). Two-component CARC and epoxy paints are used at CCAD. The CARC paint is lead- and chromium-free, but the epoxy primers, which are mandated by AVSCOM, contain both of these metals. All paint sludge and dust from painting operations are therefore hazardous.

2.3 LETTERKENNY ARMY DEPOT (LEAD)

2.3.1 Depot Description

Letterkenny Army Depot (LEAD), which is located in south central Pennsylvania near the city of Chambersburg, is responsible for receiving, storing, maintaining, and issuing general supplies and ammunition in support of DOD activities. This work includes the repair and refurbishment of wheeled and tracked combat vehicles, missile systems, fire-control systems, and associated secondary items. Paint wastes are generated during both paint-stripping and paint-application repair activities. Table 2-3 presents a summary of paint waste generation rates at LEAD.

2.3.2 Abrasive-Blasting Wastes

Four types of abrasive blast media are used at LEAD: walnut shells, steel shot, plastic beads, and glass beads. In 1989, a combined total of approximately 374 tons of abrasive shot-blast waste was generated by LEAD. The approximate breakdown by media type is shown in Table 2-3. Currently, the spent walnut-shell shot-blast waste generated at LEAD is not considered a RCRA hazardous waste. It is, however, classified as an industrial waste in Pennsylvania. According to State regulations, this

TABLE 2-3. SUMMARY OF ANNUAL PAINT WASTE GENERATION AT LEAD[a]

Waste type	Generation rate, tons	Percent of total
Abrasive blast wastes		
Walnut shells	261	43
Steel shot	90	15
Plastic beads	16	3
Glass beads	7	1
Chemical-stripping wastes		
Methylene chloride	17	3
Sodium hydroxide	23	4
Paint application wastes		
Nannapeel	8	1
Paint booth filters	45	7
Paint arresters	10	2
Thinner/paint sludge	25	4
Water/primer	19	3
Paint/solvent	<1	<0.5
Epoxy/primer	14	2
Paint chips	1	<0.5
Paint solvent waste	9	1
Paint waste	9	1
Paint solvent	3	<0.5
Sanding booth filters	11	2
Sanding paper and dirt	2	<0.5
Paper/tape/alum. foil	<1	<0.5
Trash with CARC paint	27	4
Paint, air hoses	<1	<0.5
Paint sludge/dirt/oil	2	<0.5
Paint cans in speedy dry	1	<0.5
Paint waste thinner	4	<1
Total	607	100

[a] Source: PEI Associates, Inc. Draft Report - Pilot Study of Paint Waste Treatment Technology Phase II Report Recommendations for Technology Development. Prepared for U.S. Army Toxic and Hazardous Materials Agency under Army Contract No. DAAA15-88-D-0001. Task Order No. 0001. September 1990.

material must be disposed of in an industrial landfill. All of the other shot-blast wastes are disposed of as hazardous waste.

2.3.3 Chemical-Stripping Wastes

Chemical paint stripping at LEAD is accomplished by treating parts in either a methylene chloride/formic acid stripper or in a sodium hydroxide-based alkaline paint stripper. The physical state of the chemical-stripping waste residuals varies from a thick mixture of paint solids and strippers to free-flowing liquids. In 1989, LEAD generated approximately 40 tons of chemical-stripping residuals. All chemical-stripping residuals are currently disposed of as hazardous waste.

2.3.4 Paint-Application Wastes

in 1989, LEAD generated approximately 193 tons of paint application wastes. The paint-application wastes generated by LEAD vary from waste liquid thinners and congealed paint to paint spray-booth filters and miscellaneous trash and debris. All of the paint-application wastes were considered hazardous because they were ignitable or EP Toxic according to RCRA definitions.

2.4 RED RIVER ARMY DEPOT (RRAD)

2.4.1 Depot Description

Red River Army Depot (RRAD) is located just west of Texarkana, Texas. Its primary mission is to repair armored personnel carriers. Paint wastes are generated during both paint-stripping and paint-application repair activities of this equipment. Table 2-4 presents a summary of paint waste generation rates at RRAD.

2.4.2 Abrasive-Blasting Wastes

Five types of abrasive-blast media are used at RRAD: stainless steel shot, steel shot, sand, glass beads, and walnut shells. Most of the blasting operations are associated with the vehicle hulls and are done with stainless steel shot media. A small amount of walnut shell media is used in small blast hand cabinets for use on nonferrous metal parts. The depot currently does not use plastic media because this material is not believed to be aggressive enough for paint removal. In 1989, RRAD generated a combined total of approximately 433 tons of abrasive shot-blast waste. An estimated 5 percent (22 tons) of the abrasive blast wastes generated in 1989 resulted from the

TABLE 2-4. SUMMARY OF ANNUAL PAINT WASTE GENERATION AT RRAD[a]

Waste type	Generation rate, tons	Percent of total
Abrasive blast wastes		
Stainless steel shot, steel shot, sand, and glass beads	411	64
Walnut shells	22	3
Chemical stripping wastes		
Methylene chloride	1	<0.5
Sodium hydroxide	62	10
Paint application wastes		
Paint mixed with thinners	145	22
Thinners and solvents only	3	<0.5
Total	644	100

[a] Source: Personal communications from J. Gross of RRAD, November 14, 1990, and from T. Funderburg and R. Foster of RRAD, November 15, 1990.

use of walnut shell media. The majority of shot blast wastes generated at RRAD are disposed of as hazardous waste.

2.4.3 Chemical-Stripping Wastes

Chemical paint stripping is accomplished at RRAD by treating parts in either a methylene chloride/formic acid stripper or in a sodium hydroxide-based (55 percent NaOH) alkaline paint stripper (TT-R-230). Beginning in 1990, RRAD will replace the methylene chloride/formic acid stripper with a dichlorobenzene (40 to 50 percent) stripper called HT-22-32. Most of the chemical paint stripping is now conducted with the sodium hydroxide stripper. In 1989, RRAD generated approximately 63 tons of chemical-stripping residuals. All chemical-stripping residuals are currently disposed of as hazardous waste.

2.4.4 Paint-Application Wastes

Painting operations at RRAD are conducted in both water-wall paint booths and in booths equipped with dry filters. In 1989, RRAD generated approximately 148 tons of paint-application wastes. The majority of this waste material is paint sludge

of paint-application wastes. The majority of this waste material is paint sludge generated in the water-wall paint booths. All of the paint-application wastes are currently disposed of as hazardous waste.

2.5 TOBYHANNA ARMY DEPOT (TOAD)

2.5.1 Depot Description

Tobyhanna Army Depot (TOAD), which is located in northeast Pennsylvania near the city of Tobyhanna, is responsible for maintaining and supplying communication and electronic equipment in support of DOD activities. The depot preserves, overhauls, rebuilds, modifies, and repairs items such as electronic components, generators, communication shelters, and 2-ton and 5-ton trucks. Paint wastes are generated during both paint-stripping and paint-application repair activities. Table 2-5 presents a summary of paint waste generation rates at TOAD.

TABLE 2-5. SUMMARY OF ANNUAL PAINT WASTE GENERATION AT TOAD[a]

Waste type	Generation rate, tons	Percent of total
Abrasive blast wastes		
Aluminum oxide/steel shot	151	68
Residue (coveralls, gloves, sandpaper)	13	6
Chemical-stripping wastes		
Methylene chloride/sodium hydroxide	4	2
Paint-application wastes		
Paint sludge from water-wall paint spray booths	34	15
Paint booth filters	14	6
Paint thinner	6	3
Total	222	100

a Source: PEI Associates, Inc. Trip Reports - Hazardous Waste Minimization and Control at Army Depots. Prepared for U.S. Army Toxic and Hazardous Materials Agency under Army Contract No. DAAA15-88-D-0001. Task Order No. 0004. August 1989.

2.5.2 Abrasive-Blasting Wastes

Abrasive paint stripping at TOAD is conducted by aluminum oxide blasting, steel shot blasting, and hand sanding (on shelters). In 1988, TOAD generated approximately 164 tons of abrasive-blast waste. Currently, the abrasive-blast waste generated at TOAD is disposed of as hazardous waste.

2.5.3 Chemical-Stripping Wastes

Compared with other depots, TOAD does very little chemical paint stripping. A single, small (500-gallon) chemical-stripping tank is used for stripping small parts. Chemical paint stripping is accomplished with either a methylene chloride/formic acid stripper or with a sodium hydroxide-based alkaline paint stripper. In 1988, TOAD generated approximately 4 tons of chemical stripping residuals. All chemical-stripping residuals are currently disposed of as hazardous waste.

2.5.4 Paint-Application Wastes

In 1988, TOAD generated approximately 54 tons of paint application wastes. The major paint-application waste generated at TOAD is sludge from water-wall paint-spray booths. All of the paint-application wastes are considered hazardous because they are ignitable or EP Toxic according to RCRA definitions.

2.6 TOOELE ARMY DEPOT (TEAD)

2.6.1 Depot Description

Tooele Army Depot (TEAD) is located in Utah, about 36 miles southwest of Salt Lake City and 3 miles south of Tooele. Its primary mission is to maintain and supply combat vehicles (primarily trucks), trailers, electrical generators, and related mobile equipment. Paint wastes are generated during both paint-stripping and paint-application repair activities of the preceding equipment. Table 2-6 presents a summary of paint waste generation rates at TEAD.

2.6.2 Abrasive-Blasting Wastes

Four types of abrasive blast media are used by TEAD: steel shot, aluminum oxide, walnut shells, and glass beads. In 1988, TEAD generated a combined total of approximately 197 tons of abrasive shot-blast waste. Table 2-6 presents the approximate breakdown by media type. Currently, all shot-blast wastes are disposed of as hazardous waste.

TABLE 2-6. SUMMARY OF ANNUAL PAINT WASTE GENERATION AT TEAD[a]

Waste type	Generation rate, tons	Percent of total
Abrasive blast wastes[b]		
Steel shot	80	11
Aluminum oxide	66	9
Walnut shells	50	7
Glass beads	1	<.5
Chemical-stripping wastes[c]		
Sodium hydroxide solution	324	43
Sodium hydroxide sludge	16	2
Carbon remover/stripper	33	4
Paint-application wastes[c]		
CARC paint sludge	122	16
CARC thinner residue	23	3
Paint filters	22	3
Enamel paint sludge	14	2
Total	751	100

a Source: PEI Associates, Inc. Trip Reports - Hazardous Waste Minimization and Control at Army Depots. Prepared for U.S. Army Toxic and Hazardous Materials Agency under Army Contract No. DAAA15-88-D-0001. Task Order No. 0004. August 1989.

b Source: Personal communication from K. Wong of TEAD, November 15, 1990.

c Paint sludge wastes and paint stripper/thinner residues were assumed to weigh 730 and 550 lb/drum, respectively. Sodium hydroxide solution wastes were assumed to weigh 11 lb/gal.

2.6.3 Chemical-Stripping Wastes

The majority of chemical paint stripping at TEAD is accomplished by treating parts in tanks with a sodium-hydroxide-based alkaline paint stripper. The tanks are occasionally pumped out as needed and disposed of as hazardous waste. A total of 43 drums (approximately 16 tons) of sludge and 58,927 gallons (approximately 324 tons) of sodium hydroxide solution were generated from stripping operations in 1988. In addition to sodium hydroxide, TEAD also uses a carbon-remover compound for paint stripping. A total of 118 drums (approximately 33 tons) was generated in 1988. Small quantities of a methylene-chloride-based stripper are also used. The stripper is brushed on parts on which small areas of paint are left after abrasive cleaning. In

1988, TEAD generated 373 tons of chemical-stripping residuals. All chemical-stripping residues are currently disposed of as hazardous waste.

2.6.4 Paint-Application Wastes

In 1988, TEAD generated approximately 181 tons of paint-application wastes. The approximate breakdown by type is shown in Table 2-6. All of the paint-application wastes are considered hazardous because they are ignitable or EP Toxic according to RCRA definitions.

2.7 PAINT WASTE CHARACTERIZATION SUMMARY

Table 2-7 presents a summary of paint waste generation rates at the six major depots. The portion of the waste stream considered to be incinerable is shown in parentheses.

TABLE 2-7. SUMMARY OF ANNUAL PAINT WASTE GENERATION AT DEPOTS

Depot name	Total, tons	Abrasive wastes, tons	Chemical wastes, tons	Paint wastes, tons
ANAD	2063 (676)[a]	1627 (240)	156 (156)	280 (280)
CCAD	516 (234)	327 (45)	57 (57)	132 (132)
LEAD	607 (510)	375 (277)	40 (40)	193 (193)
RRAD	644 (233)	433 (22)	63 (63)	148 (148)
TOAD	222 (71)	164 (13)	4 (4)	54 (54)
TEAD	751 (280)	197 (50)	373 (49)	181 (181)
Total	4803 (2004)	3123 (647)	693 (369)	988 (988)

[a] Portion of waste stream considered to be incinerable is shown in parentheses.

SECTION 3

INCINERATION SYSTEMS COST ESTIMATES

Cost parameters for incineration systems were developed to provide a basis for the economic evaluation of alternative incineration strategies. The cost parameters form an input to the strategy-evaluation model. This model is used to determine the sensitivity of the incineration system costs to factors such as system size, number of units, and annual operating hours. The objective of the strategy-selection model is to provide the lowest cost solution that meets the given set of constraints. The strategy-selection model requires incineration cost as one of the input parameters to optimize the overall strategy cost. The optimization process is described in detail in Section 4.

Cost functions for paint waste incineration systems are developed in this section. The functions are developed by the model plant approach. Three representative incineration system sizes are selected, and costs (in terms of $/ton of waste) are estimated for each system. Cost functions indicating the cost/size relationship are then obtained by the linear regression technique. The selection of representative system sizes is discussed first, followed by the cost methodology. The capital and annual costs are presented along with the estimating bases and assumptions.

3.1 SELECTION OF MODEL PLANT SIZES

Selection of model sizes is based on incineration capacities required at the individual depots. Table 3-1 represents the annual incinerable paint waste quantities at the six candidate depots, rounded off to the next 10th for the analysis. The total incinerable paint waste quantity for the six candidate depots is 2000 tons.

The model plant sizes selected for the analysis have waste incineration capacities of 0.5, 1, and 2 tons/h. The annual waste incineration capacity of a plant will depend on the hours of operation of the plant. By selecting different hours of operation, various annual incineration capacities can be obtained. Assuming a lower limit of incineration operation of 2 hours/week and 50 weeks/yr and an upper limit of 40 hours/week and 50 weeks/yr, the selected model plants can provide an annual incineration capacity ranging from 50 to 4000 tons/yr. By using the proper combination of plant size and annual operating hours, the paint waste incineration requirements of the individual depots can be met.

TABLE 3-1. SUMMARY OF ANNUAL PAINT WASTE QUANTITIES

Depot	Actual paint waste quantity, tons/yr	Assumed quantity, tons/yr
Anniston	676	680
Corpus Christi	234	230
Letterkenny	510	510
Red River	233	230
Tobyhanna	71	70
Tooele	280	280
Total	2004	2000

Table 3-2 presents the parameters of the model plants selected for the analysis. The data in Table 3-2 are derived from the rotary kiln pilot test results performed by PEI Associates, Inc. (now IT Corporation). The pilot test methodology and results are documented in a report entitled "Pilot-Scale Testing of Paint Waste Incineration," dated June 1989. The heat input and exhaust flow rates for the model plants were calculated assuming a linear dependence of these parameters on the waste feed rate. The pilot-plant waste feed rate was 195 lb/h and the heat input rate was indicated to be between 2 and 3 million Btu/h. The heat input rates for the model plants were based on an average of these values and were rounded off. A similar procedure was used to estimate the exhaust flow rates for the model plants.

As shown in Table 3-1, the annual paint waste incineration capacities required at the depots range from 70 to 680 tons. Model Plant 1 can meet the 70 to 680 tons/yr capacity requirement if operated at the appropriate annual operating hours. Similarly, Model Plants 2 and 3 can meet the entire 2000 tons/yr depot requirement if the appropriate annual operating hours are chosen. A similar procedure can be used for other incineration capacity requirements. The individual depots will normally select the annual operating hours suitable for their establishments and will then select the plant size that will provide the required incineration capacity.

TABLE 3-2. PARAMETERS OF MODEL PLANTS

Parameter	Plant 1	Plant 2	Plant 3
Incineration capacity, ton/h	0.5	1	2
Heat input rate, million Btu/h	12.5	25	50
Exhaust flow rate, dscfm	5,000	10,000	20,000
Kiln temperature, °F	1,800	1,800	1,800
Temperature in secondary combustion chamber, °F	2,000	2,000	2,000
Annual incineration capacity, tons/yr			
100 h/yr operation	50	100	200
400 h/yr operation	200	400	800
1,000 h/yr operation	500	1,000	2,000
2,000 h/yr operation	1,000	2,000	4,000

Selection of annual operating hours will require consideration of several factors. Ideally, the incineration system will be operated on a continuous basis without interruptions. This will result in more reliable and efficient operation because preheating and cooldown of the system will be less frequent; however, this also means that a facility must accumulate sufficient quantities of waste to feed the system. It will also require the installation of adequate waste storage capacity for the planned incineration cycle. For example, a facility generating 100 tons/yr of waste may install a 0.5 ton/h unit and plan to operate it 200 hours a year. The facility may obtain the 200 hours during a year by operating the unit four or five time periods averaging 40 to 50 hours each. The nature of operation will vary from site to site depending upon the waste storage capacity, weather, and other site-specific factors.

3.2 COST ESTIMATION

Capital and annual operating costs are estimated for the model plants to formulate the cost relationships. The cost estimates presented in this section are study estimates, also referred to as "factored" estimates. The accuracy of these estimates is expected to be ±30 percent. Study estimates are used for general evaluations and for comparing alternatives. They allow screening of available alternatives, and they

provide a basis for limiting the number of alternatives that warrant a more detailed evaluation.

The capital and operation and maintenance (O&M) costs are based primarily on a report by Acurex Corporation, Mountain View, California, entitled "Capital and O and M (Operation/Maintenance) Cost Relationships for Hazardous Waste Incineration." This report was prepared for the Industrial Environmental Research Laboratory of the U.S. Environmental Protection Agency, Cincinnati, Ohio (EPA-600/2-84-175 October 1984). It presents the cost relationships for individual equipment items of the rotary kiln incineration system. Figure 3-1 presents a schematic of the rotary kiln incineration system along with the air pollution control system on which the Acurex costs are based.

3.2.1 Capital Costs

Capital cost covers all the initial costs associated with installation of a facility, including physical equipment and facilities and working capital reserve that must be available to pay salaries, to keep fuel and raw materials inventory on hand, and to handle other special items that require direct cash outlay. The capital cost estimate also includes the costs the owner incurs for the equipment and services supplied by existing resources. The capital cost represents the "turn-key" cost up to the successful commissioning date of the facility.

The capital cost is generally categorized as direct, indirect, and other. The purchase cost of the plant equipment and the cost of installation are considered direct costs. The equipment purchase price normally does not include the freight charges. Installation costs cover the interconnection of the system, which involves piping, electricity, and other items needed for successful operation of the system. Also included as direct costs are the costs of foundations, supporting structures, enclosures, ducting, control panels, instrumentation, insulation, painting, and similar items. Costs for supporting facilities such as site preparation, roads, rail facilities, and electrical substation are also included in the direct cost estimate.

The indirect costs account for the expenditures necessary for items such as field overheads, engineering and supervision, freight, spares, and system startup. These expenses are required on a plant-wide basis and cannot be attributed to specific system components.

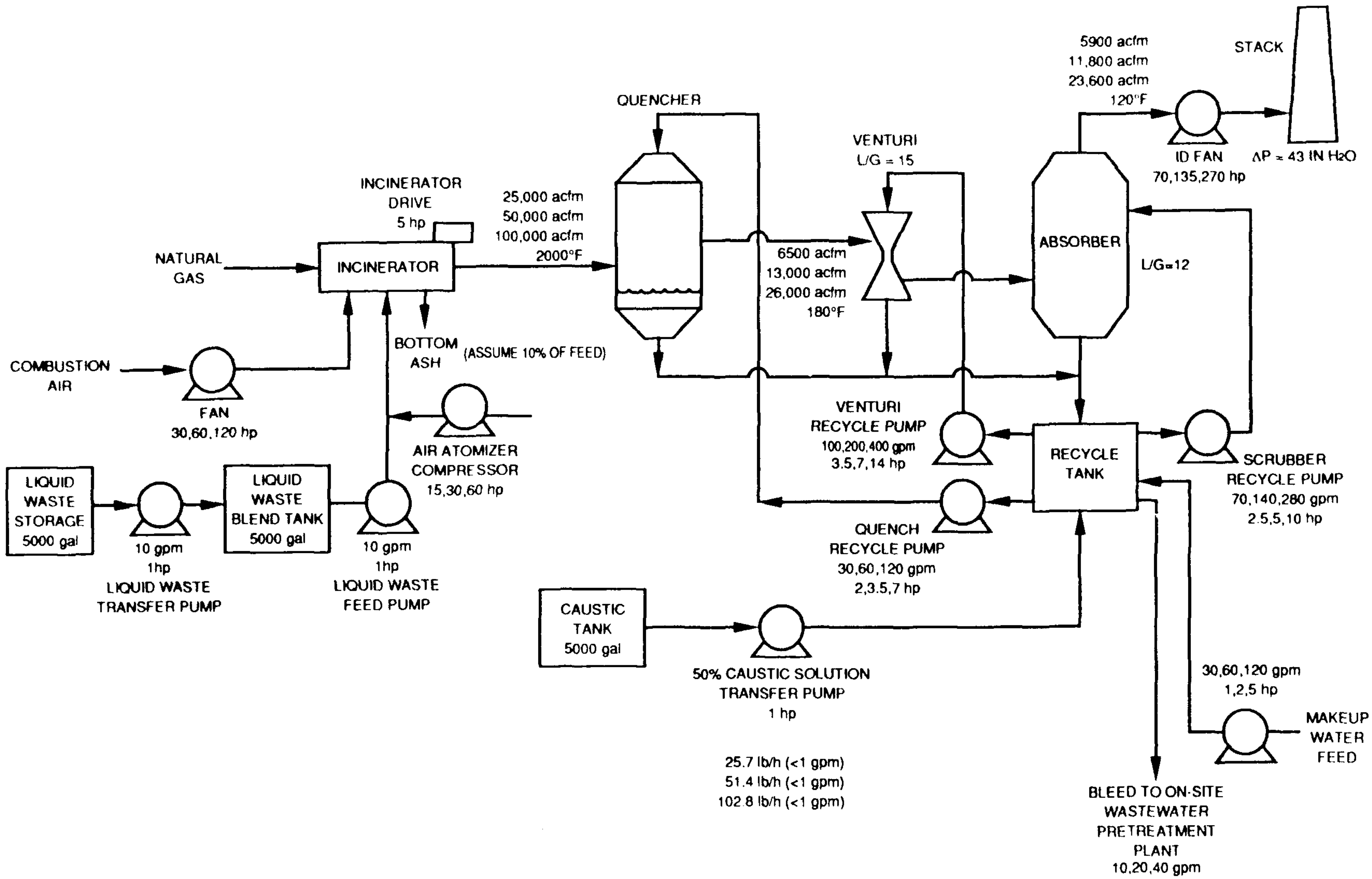


Figure 3-1. Schematic of rotary kiln incineration system and air pollution control equipment.

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The capital cost estimate also includes costs such as contingencies, contractor fees, permit expenses, and working capital. These items, generally referred to as "other costs," are estimated as percentages of direct and indirect costs.

The capital costs of the model plants are calculated by using the equations for the individual equipment items from the Acurex report. The total direct costs are obtained for the system by adding the individual costs. The indirect costs and other costs are calculated as percentages of the direct cost. The base year for the Acurex cost equations is 1982. The individual costs were escalated to June 1990 dollars by using cost index data published by Chemical Engineering. Table 3-3 shows the bases and assumptions used for the capital costs.

TABLE 3-3. CAPITAL COST BASES AND ASSUMPTIONS

Base year for capital costs	June 1990
Escalation factor (1982 -1990)	1.137
Indirect Cost Bases:	
- Field overhead	10% of direct cost
- Engineering and supervision	8% of direct cost
- Freight	3% of equipment
- Allowance for shakedown	10% of direct cost
- Spares	5% of equipment
Other Cost Bases:	
- Contingency	10% of direct + indirect
- Contractor's fee	8% of direct + indirect + contingency
- Permits	$100,000

3.2.2 Annual Costs

Annual costs represent the cost of owning and operating the system on an annual basis. Included are operation and maintenance costs and capital recovery costs. Operation and maintenance costs represent the day-to-day costs of operating and maintaining the system in a proper state of repair. The capital recovery charges consist of costs associated with the recovery of the initial capital investment.

The annual costs are estimated as direct and indirect costs. The direct costs consist of items that are directly dependent on the operating schedule of the system. Included are items such as raw materials, utilities, and labor. The costs of raw

materials and utilities are obtained by multiplying the annual consumption rates by the unit price of the individual item. For the incineration systems, fuel will be a major component of the utilities. The labor category includes operating and supervisory labor costs. The costs of supplies such as lubricants, cleaning chemicals, and other consumables are also included in the direct costs. The cost of supplies is estimated as a percentage of the capital investment. The direct cost of the incineration system will also include the cost of ash disposal. The direct cost does not include, however, the cost for pretreatment of incinerator wastewater. This cost is assumed to be negligible compared with current depot wastewater pretreatment requirements.

The indirect annual costs include payroll overhead, administration overhead, and capital charges. Payroll overhead consists of employee fringe benefits, health insurance, and similar costs. This cost is estimated to be 50 percent of the direct labor cost. The administration costs consist of the salaries and fringe benefits of administrative employees. Because these costs are expected to be insignificant for the incineration systems, they are assumed to be zero. Capital recovery charges are based on a 10-year equipment life and a 10 percent interest rate.

Table 3-4 summarizes the bases and assumptions for the annual costs.

TABLE 3-4. ANNUAL COST BASES AND ASSUMPTIONS

Sodium hydroxide solution	\$300/ton
Electricity	\$0.07/kWh
Natural gas	\$3.50/million Btu
Water	\$1/1000 gal
Operating labor	\$15/h plus 40% for overhead
Supervision	20% of Operating labor
Maintenance	1% of Capital investment
Ash disposal	\$200/ton
Waste transportation	\$0.20/ton-mile
Payroll overhead	50% of O & M labor
Administration	80% of O & M labor
Capital recovery	10 year at 10%

3.2.3 Model Plant Costs

The capital costs of the model plants (as shown in Table 3-5) include a rotary kiln incineration unit, an air pollution control system needed to comply with the applicable air emission regulations, and ancillary equipment. The ancillary equipment includes items such as conveyors, storage tanks, pumps, piping, and ductwork.

TABLE 3-5. CAPITAL COSTS OF MODEL PLANTS (1990 DOLLARS)

	Plant 1	Plant 2	Plant 3
DIRECT COSTS			
Equipment:			
Rotary kiln unit	837,000	1,165,000	1,623,000
Air emission control system	234,000	384,000	632,000
Ancillary equipment	54,000	77,000	113,000
Subtotal, equipment	1,125,000	1,626,000	2,368,000
Installation	619,000	894,000	1,302,000
TOTAL DIRECT COST	1,744,000	2,520,000	3,670,000
INDIRECT COSTS			
Field overhead	174,000	252,000	367,000
Engineering and supervision	140,000	202,000	294,000
Freight	34,000	49,000	71,000
Allowance for shakedown	174,000	252,000	367,000
Spares	56,000	81,000	118,000
TOTAL INDIRECT COST	578,000	836,000	1,217,000
Contingency	232,000	336,000	489,000
Contractor's fee	204,000	295,000	430,000
Permits	100,000	100,000	100,000
TOTAL CAPITAL INVESTMENT	2,858,000	4,087,000	5,906,000

The capital cost of Model Plant 1 is estimated to be \$2.9 million. The costs of Model Plants 2 and 3 are estimated to be \$4.1 million and \$5.9 million, respectively. These costs are used as a basis for calculating the capital recovery charges in the annual costs.

The annual costs of the model plants are shown in Table 3-6. The costs in this table are based on 400 operating hours per year. The costs do not include a waste transportation cost because the waste is treated on site. The annual costs for Model Plants 1, 2, and 3 are estimated to be \$537,400, \$770,200, and \$1,125,500, respectively. The respective annual costs per ton of waste processed are \$2687, \$1926, and \$1407.

TABLE 3-6. ANNUAL COSTS OF MODEL PLANTS (1990 DOLLARS)

	Plant 1	Plant 2	Plant 3
DIRECT COSTS			
RAW MATERIALS:			
Sodium hydroxide solution	3,400	6,800	13,600
UTILITIES:			
Natural gas	9,500	19,000	38,100
Electricity	2,800	5,600	11,300
Water	700	1,400	2,900
LABOR:			
Operating labor	8,400	8,400	8,400
Supervision	1,700	1,700	1,700
Maintenance	28,600	40,900	59,100
Ash disposal	4,000	8,000	16,000
TOTAL DIRECT COST	59,100	91,800	151,100
INDIRECT COSTS			
Payroll overhead	5,100	5,100	5,100
Administration	8,100	8,100	8,100
Capital recovery	465,100	665,200	961,200
TOTAL INDIRECT COST	478,300	678,400	974,400
TOTAL ANNUAL COST	537,400	770,200	1,125,500

3.3 COST FUNCTION DEVELOPMENT

As a means of developing cost functions for the incineration systems, annual operating costs for different operating hours were calculated for each model plant. Table 3-7 shows the annual costs for the model plants for five different operating hours. The annual costs are calculated for 100, 200, 400, 1000, and 2000 operating hours per year. Figures 3-2 through 3-4 schematically show the annual cost/operating hour relationship for each model plant.

TABLE 3-7. WASTE QUANTITIES AND ANNUAL COSTS FOR VARYING OPERATING HOURS

	Plant 1		Plant 2		Plant 3	
Annual operating hours	Waste processed, tons	Annual cost, $/ton of waste processed	Waste processed, tons	Annual cost, $/ton of waste processed	Waste processed, tons	Annual cost, $/ton of waste processed
100	50	10,092	100	7,222	200	5,233
200	100	5,155	200	3,690	400	2,682
400	200	2,687	400	1,926	800	1,407
1,000	500	1,206	1,000	866	2,000	641
2,000	1,000	712	2,000	513	4,000	386

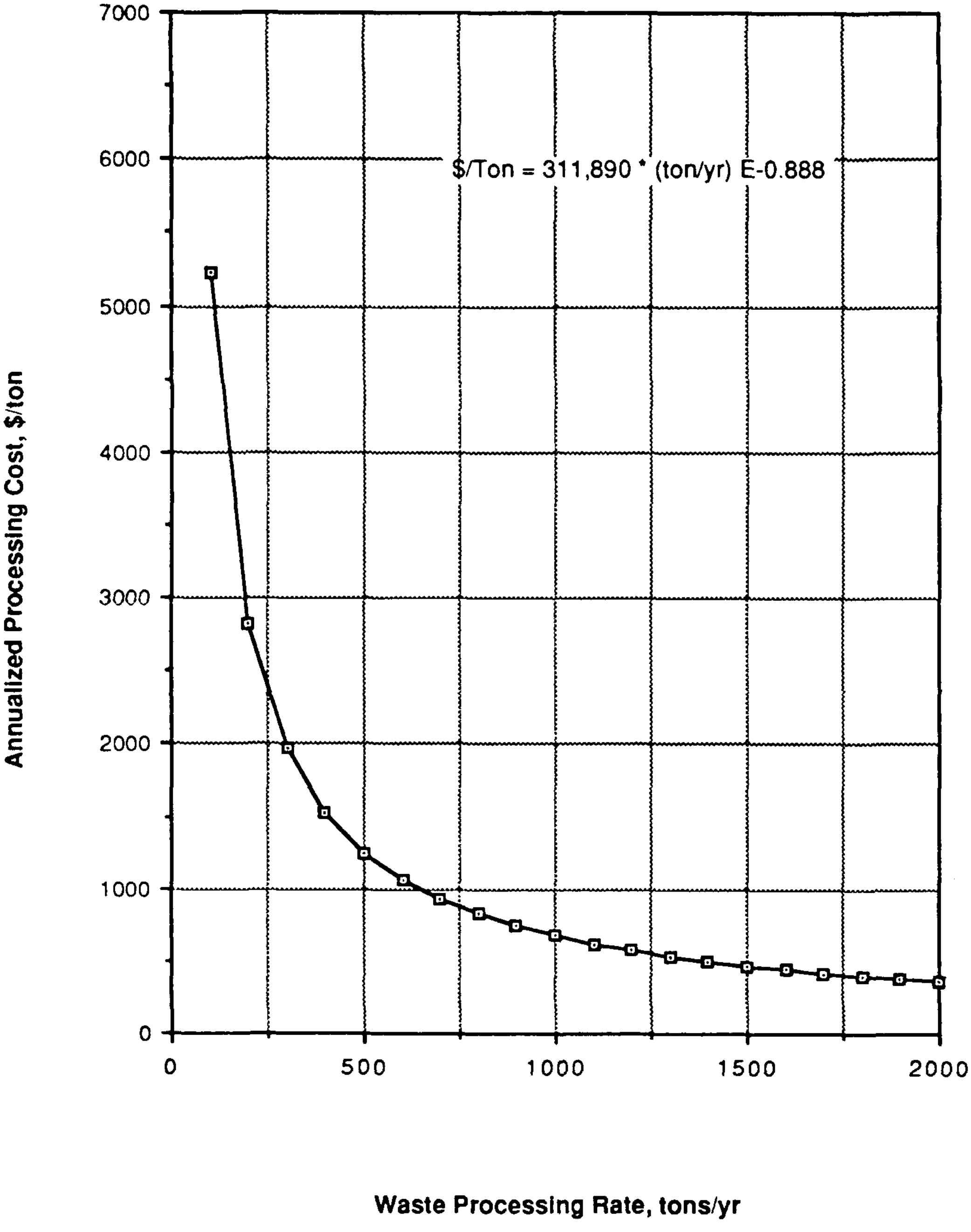

Figure 3-2. Rotary kiln annual cost (0.5 ton unit)

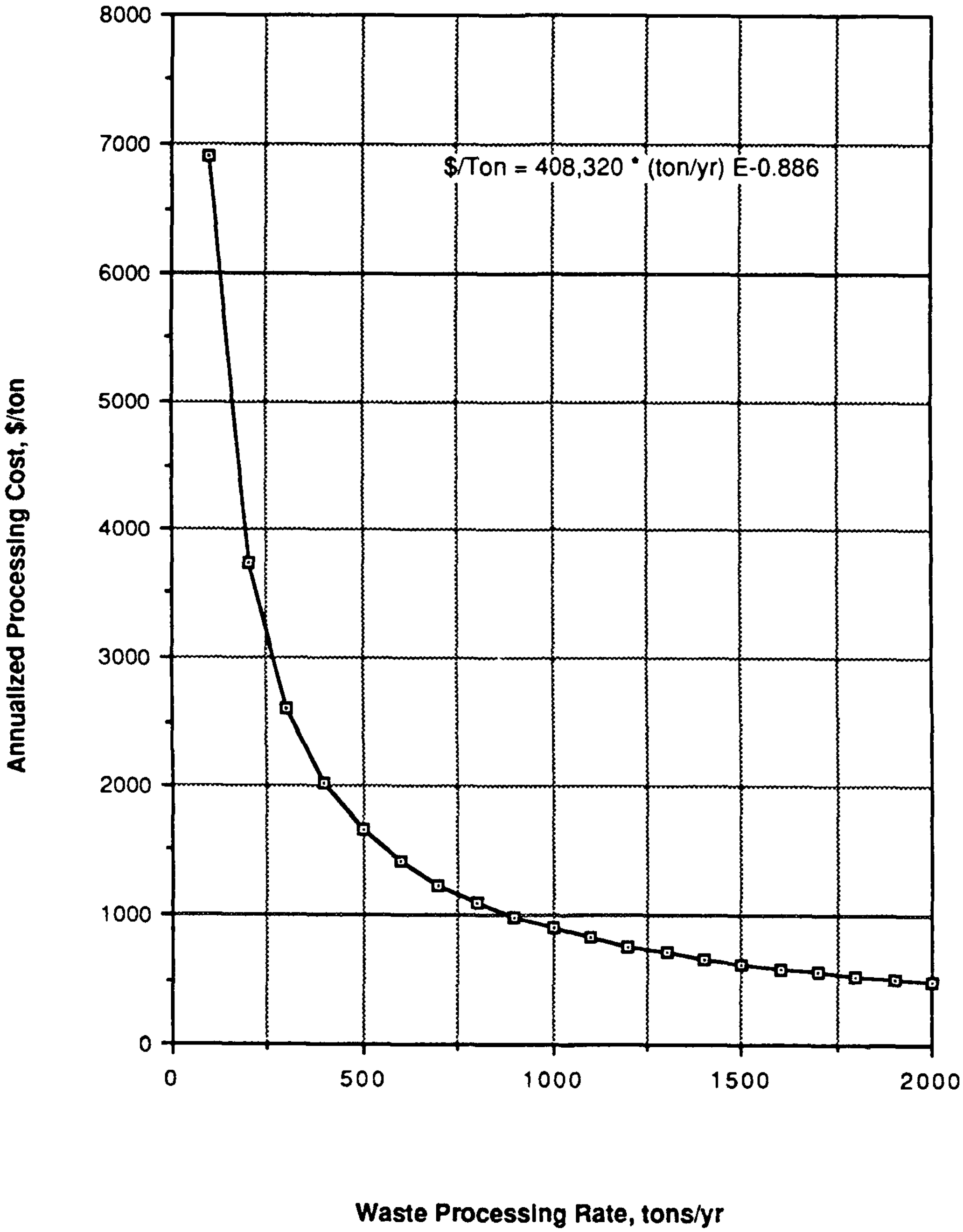

Figure 3-3. Rotary kiln annual cost (1.0 ton unit)

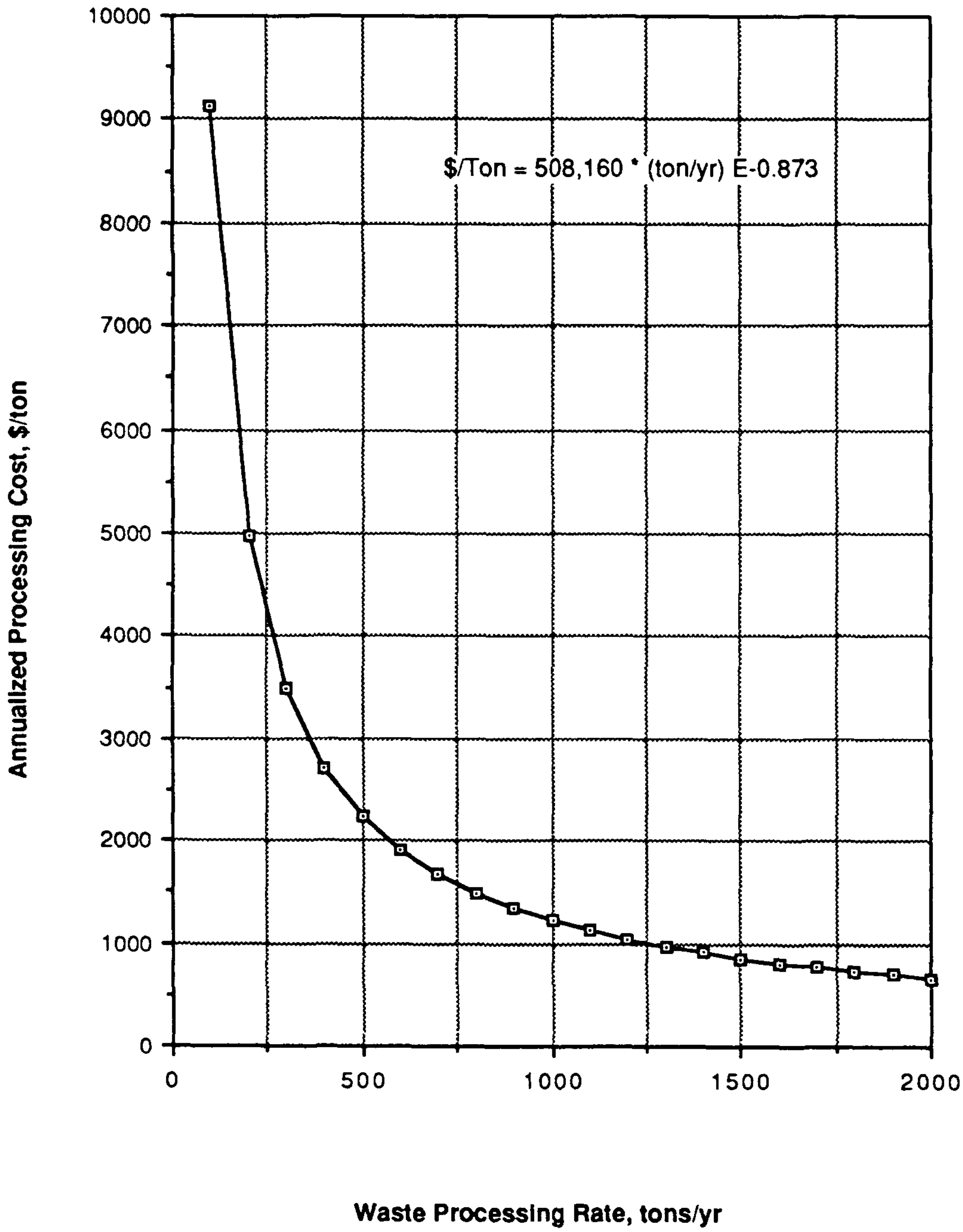

Figure 3-4. Rotary kiln annual cost (2.0 ton unit)

SECTION 4

COST ANALYSIS

To determine the most cost-effective means of incinerating paint waste at the six depots, the cost relationships developed in Subsection 3.3 were used to perform a cost analysis of the following potential options: 1) locating an incinerator at each depot; 2) locating an incinerator at a single site and transporting waste from other depots to this location; and 3) using multiple units at two or more depots. The following subsections present the results of that analysis.

4.1 MODEL PLANT SIZE SELECTION

Before the annual cost analysis could be performed on the preceding options, it was first necessary to determine which model plant size would be used for each option. On the basis of the annual cost/operating hour relationships developed in Subsection 3.3 and shown in Figures 3-2 through 3-4, the 0.5-ton unit had the lowest $/ton annual cost because the cost relationships seem to be capital cost driven. The annual operating cost in this analysis was small compared with the capital recovery factor because paint waste quantities were relatively low and annual operating hours were limited. Basically, the larger units only become cost-effective when allowed to operate more than one shift per day and 5 days per week (i.e., greater than 2080 hours per year). For this reason, only Model Plant 1 (0.5-ton) and Model Plant 2 (1.0-ton) were used in the annual cost analysis. Because individual depot generation rates range from 70 to 680 tons per year, the 0.5-ton unit was chosen as the model plant size for Option 1. For Option 2, with a total waste generation rate of 2000 tons per year, the 1.0-ton unit was chosen as the model plant size so as to be within the 2080 annual operating hour constraint. On the basis of geographic location and individual waste generation rates, it was determined that the combined waste generation rates for multiple sites (typically less than 1000 tons per year) could be satisfied using Model Plant 1 (0.5-ton unit).

4.2 COST ANALYSIS FOR LOCATING AN INCINERATOR AT EACH DEPOT

The cost analysis for locating an incinerator at each site was based on the use of a 0.5-ton/hour unit (i.e., Plant 1). Table 4-1 presents the annual cost for each 0.5-ton unit for the six depots. Because no paint waste material is transported,

transportation costs are zero. The total annual cost for operating six 0.5-ton incinerators at Anniston, Corpus Christi, Letterkenny, Red River, Tobyhanna, and Tooele is estimated to be $3,509,620. The total respective annual cost per ton of waste processed is $1755.

TABLE 4-1. ANNUAL COSTS FOR 0.5-TON/HOUR UNIT AT EACH DEPOT

	ANAD	CCAD	LEAD	RRAD	TEAD	TOAD	Total
Incineration cost, $	647,504	573,476	626,974	573,476	501,941	586,250	3,509,620
Transportation cost, $	0	0	0	0	0	0	0
Total	647,504	573,476	626,974	573,476	501,941	586,250	3,509,620
$/ton	952	2,493	1,229	2,493	7,171	2,094	1,755

4.3 COST ANALYSIS FOR LOCATING AN INCINERATOR AT A SINGLE SITE

The cost analysis for locating an incinerator at a single site was based on the use of a 1.0-ton/hour unit (i.e, Plant 2). The annual treatment cost for operating a 1.0-ton unit at a single site treating 2000 tons per year is estimated to be $971,221. Table 4-2 presents the total annual costs, including transportation cost of transporting paint waste material from five depots to a single site location. The annual cost figures range from $616/ton to $884/ton. Transportation costs are based on the mileages presented in Figure 2-1 and a transportation fee of $0.20/ton-mile. Anniston was estimated to be the most economical site location for handling the entire paint waste generation throughput for all six depots. This is a function of being the largest generator of incinerable paint waste material (approximately 34 percent) and having a central geographic location.

TABLE 4-2. ANNUAL COSTS FOR 1.0-TON/HOUR UNIT AT SINGLE DEPOT

	ANAD	CCAD	LEAD	RRAD	TEAD	TOAD
Incineration cost, $	971,221	971,221	971,221	971,221	971,221	971,221
Transportation cost, $	260,620	505,700	304,760	332,420	797,520	358,880
Total	1,231,841	1,476,921	1,275,981	1,303,641	1,768,741	1,330,101
$/ton	616	738	638	652	884	665

4.4 COST ANALYSIS FOR LOCATING AN INCINERATOR AT MULTIPLE SITES

The cost analysis for locating an incinerator at multiple sites was based on the use of a 0.5-ton/hour unit (i.e, Plant 1). Two variations of this analysis were investigated. The first analysis involved placing an incinerator at Anniston, Letterkenny, and Tooele, based on geographic proximity (Option 3A). The second variation of Option 3 involved placing an incinerator at Anniston, Letterkenny, and Red River (Option 3B). This option considered more closely the effect of centralizing waste generation versus geographic proximity. Tables 4-3 and 4-4 present the total annual costs, including transportation for both variations of Option 3. The total annual costs for Options 3A and 3B were estimated to be $967/ton to $998/ton. Again, transportation costs are based on the mileages presented in Figure 2-1 and a transportation fee of $0.20/ton-mile. On the basis of the two variations of Option 3, the estimated amounts indicate that the use of multiple sites will have higher annual operating costs compared with the use of a single site, but lower costs compared with the use of incinerators at every site.

TABLE 4-3. ANNUAL COSTS FOR 0.5-TON/HOUR UNIT AT MULTIPLE SITES--OPTION 3A

	ANAD, CCAD, and RRAD	LEAD and TOAD	TEAD	Total
Incineration cost, $	686,080	658,470	501,941	1,846,490
Transportation cost, $	78,200	10,080	0	88,280
Total	764,280	668,550	501,941	1,934,770
$/ton	670	846	7,171	967

TABLE 4-4. ANNUAL COSTS FOR 0.5-TON/HOUR UNIT AT MULTIPLE SITES--OPTION 3B

	ANAD	LEAD and TOAD	RRAD, CCAD, and TEAD	Total
Incineration cost, $	647,504	658,470	629,681	1,935,654
Transportation cost, $	0	10,080	50,140	60,220
Total	647,504	668,550	679,821	1,995,874
$/ton	952	846	1,283	998

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Based on the results presented in Section 4, the following conclusions have been drawn:

1) The cost analysis indicated that locating an incinerator at each site for paint waste incineration is not economical in comparison with commercial disposal costs.

2) Anniston Army Depot was estimated to be the most economical site location for handling the entire paint waste generation throughput for all six depots. This is a function of being the largest generator of incinerable paint waste material and having a central geographic location. The estimated disposal cost for Anniston to handle the entire paint waste generation throughput, however, is not economical in comparison with commercial disposal costs.

3) The cost analysis indicated that locating an incinerator at multiple sites for paint waste incineration is not economical in comparison with commercial disposal costs.

5.2 RECOMMENDATIONS

Based on the results in Section 4, the following recommendations are made:

1) In order for on-site incineration to be economical, the depots need to consider burning other combustible waste streams in addition to paint wastes. The Army should also consider burning wastes from other Department of Defense facilities (Navy and Air Force).

2) Heat recovery was not considered in the cost analysis because the units could not be continuously operated because of low annual operating hours. Heat recovery could potentially be used, however, if operating hours were increased as a result of increased waste throughputs. This would aid in making waste incineration at depots more economical.